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IMPROVING ENGINEERING STUDENTS' UNDERSTANDING OF COMPONENTS OF CYBER-PHYSICAL SYSTEMS USING A TEAM PROJECT-BASED TEACHING METHOD

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Abstract. This article describes a teaching method that was used to teach second-year mechatronics and robotics students the components of cyber-physical systems. In view of the importance of team learning, the group was divided into five sub-groups (student teams) in order to increase efficiency by comparing the tasks undertaken by the teams. A line following robot was used for the teaching. This course was designed to last 48 academic hours. As a result, the students noted that after building the robot in teams, their attitude towards cyber-physical systems changed, and they became motivated to carry out larger projects related to cyber-physical systems.

Keywords: cyber-physical systems, teaching method, robot, student teams, project-based learning.

Conflict of interests. The authors declare no conflict of interests.

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УЛУЧШЕНИЕ ПОНИМАНИЯ СТУДЕНТАМИ-ИНЖЕНЕРАМИ КОМПОНЕНТОВ КИБЕРФИЗИЧЕСКИХ СИСТЕМ С ИСПОЛЬЗОВАНИЕМ МЕТОДА ОБУЧЕНИЯ, ОСНОВАННОГО НА КОМАНДНЫХ ПРОЕКТАХ

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Аннотация. В статье описывается метод обучения, который использовался для обучения студентов второго курса мехатроники и робототехники компонентам киберфизических систем. Учитывая важность командного обучения, группа была разделена на пять подгрупп (студенческих команд), чтобы повысить эффективность за счет сравнения заданий, выполняемых командами. Для обучения использовался робот, следующий за линией. Этот курс был рассчитан на 48 академических часов. В результате студенты отметили, что после создания робота в командах их отношение к киберфизическим системам изменилось, и у них появилась мотивация выполнять более масштабные проекты, связанные с киберфизическими системами.

Ключевые слова: киберфизические системы, метод обучения, робот, студенческие команды, обучение на основе проекта.

Конфликт интересов. Авторы заявляют об отсутствии конфликта интересов.

Для цитирования. Улучшение понимания студентами-инженерами компонентов киберфизических систем с использованием метода обучения, основанного на командных проектах / А. А. Чарыева [и др.] // Цифровая трансформация. 2024. Т. 30, № 2. С. 43–51. http://dx.doi.org/10.35596/1729-7648-2024-30-2-43-51.

Introduction

Oguzhan Engineering and Technology University of Turkmenistan (ETUT) was opened in 2016 and is one of the youngest universities in the country. Despite its youth, our university, which is one of the leading universities in the country, is a reporter of the Times Higher Education [1], member of CDIO [2], UI GreenMetric [3], and a number of other international organisations [4, 5]. ETUT trains engineering technologists and technicians at Bachelor's degree. The aim of the ETUT's teaching staff is to prepare a competitive specialist in their field.

At the ETUT students receive a quality education in English and Japanese in accordance with international educational standards in the majorities “Automation and control”, “Mechatronics and robotics”, “Electronics and nanoelectronics”, “Biomedical electronics”, “Physics of modern technologies”, “Technical means of data protection”, “Technologies of digital economy”, “Digital infrastructure and cybersecurity”, “Mobile and network engineering”, “Innovative economics” and etc. [6].

One of the main tasks of the academic staff of the Department of Cyber-Physical Systems (CPS) at the ETUT is to provide the students of this department with a broad modern understanding of CPS. CPS are one of the main directions of the intelligent industry that is planned to be organised in the country in the coming years.

A smart manufacturing is an industrial system that integrates modern information and communication technologies with the production environment to ensure real-time management of energy, productivity and costs in the production process at the machine, factory or enterprise level. In other words, the smart manufacturing is the production of the future, combining the imaginary and physical worlds through CPS. The capabilities of devices and sensors to transfer information between each other make it possible to build an intelligent network throughout the entire production chain [7, 8]. In order to achieve the above, there is a need for highly qualified specialists who are will be able to model CPS platforms and their production, create software using different programming languages for the interaction of modern sensors and control systems with each other, in short, engineers who can deal with CPS.

For this reason, the academic staff of the Department of CPS are striving to train personnel who will work in this new industrial sector, which will make a great contribution to the development of the country, according to modern requirements and to achieve a continuous improvement of their skills. This article describes the characteristics of the method that uses a programmable line following robot to improve the understanding of components of CPS by undergraduate students of the Department of CPS.

Literature review

To date, several researchers have conducted research into teaching methods for students with components of CPSs.

V. Gadepally et al. [9] using the existing project “Autonomous driving in mixed environments” explain to students the structure and working principle of CPS. In this paper, based on the “Autonomous driving in mixed environments” project, students are invited to develop algorithms for the CPS, “Roomba, overcoming competition”, and the results of this method are analysed through a project competition. The aim of this event is to give students the opportunity to study the components of CPS by working independently on existing scientific projects.

N. Ueter et al. [10] in their work, they teach of the Department of Computer Science and Computer Engineering students the components of CPS by building an unmanned vehicle using the project-based learning method. Project-based learning is a comprehensive programme in which students start with projects in one subject area while developing their skills in other subjects. In this article, the basic concepts of CPSs are explained to the students and the results demonstrated by the students are discussed and evaluated at the end of the project. In this methodology, students are given the opportunity to apply their theoretical knowledge, complete a project and test their work in real life to improve their cognitive skills. This method also aims to improve students' ability to work in groups on complex projects.

The work of S. A. Nelke et al. [11] is also based on the use of project-based learning methodology in teaching students the components of CPS. But the difference in their methodology is that it is aimed at teaching undergraduate students in "Industrial engineering and technology management", who practically have no knowledge about the components of CPS, about courses in electricity and programming. The authors solved this problem by teaching students about the Internet of things, one of the key components of CPS. This is because Technological Business Engineers, who are the profession of the future, will be able to work with electrical engineers and programmers, and gaining an understanding of their work, will enable them to properly manage multifaceted projects.

S. Ghosh et al. [12] use the CPS testbed, which specialises in developing a simple way to teach students the components of CPS. This testbed allows students to design, run and analyse control algorithms in various CPS. As can be seen from the teaching methods above, each institution uses different methods to teach students the components of CPS. This article describes our teaching methodology used to teach the components of CPSs to 2nd year students of "Mechatronics and robotics" at the Faculty of Cyber-physical systems.

Methodology

Teaching students about the components of CPS starts with explaining to them what the term "cyberphysical systems" means. To do this, we use Google Scholar to analyze various literature and use the most cited articles. Using several articles and writing definitions in notebooks, we discuss all these definitions together with the students. While discussing the definitions of the term CPS, we also come across a number of other terms related to CPS, and again analyse the relevant literature sources in order to understand them. This methodology allows students to better understand CPSs. In order to consolidate what has been learnt in this lesson, in the next lesson we give the students cards with the names of the terms and explore the students' concepts. If the student has not improved, more time is given and the previous activities are repeated. As an example of the definition of cyberphysical systems, consider the following definitions.

E. A. Lee [13]: "A cyber-physical system (CPS) is an orchestration of computers and physical systems. Embedded computers monitor and control physical processes, usually with feedback loops, where physical processes affect computations and vice versa".

V. Gunes et al. [14]: "Cyber-physical systems (CPSs) are complex, multi-disciplinary, physically-aware next generation engineered systems that integrate embedded computing technology (cyber part) into the physical phenomena by using transformative research approaches. This integration mainly includes observation, communication, and control aspects of the physical systems from the multi-disciplinary perspective".

R. Alguliyev et al. [15]: "Cyber-physical systems (CPS) is a system that can effectively integrate cyber and physical components using the modern sensor, computing and network technologies".

A. Humayed et al. [16]: "CPS are composed of various components in many ways. There are different hardware components such as sensors, actuators, and embedded systems. There are also different collections of software products, proprietary and commercial, for control and monitoring".

M. N. O. Sadiku et al. [17]: "A CPS has three main components: (1) a physical system, (2) networking and communication element, (3) a distributed cyber system. CPSs are designed with a set of distributed hardware, software, and network components which are embedded in physical systems and environments. The software plays the most important role; it includes all software programs for processing, filtering, and storing information. CPSs interact with the physical system through networks".

As we can see, in the definitions provided to understand the meaning of the term CPS, we find several other terms such as integrated systems, physical system, sensors, computing structure, actuators, high precision network. These new terms are also discussed throughout the course. Of course, many of these new terms have been explained in previous lessons. If these terms have not been considered before this lesson, then these new terms are also being supplemented. Once the students have learnt these terms, it remains to familiarise them with the places where they are used in the design of CPSs and the functions they perform, by seeing and "touching" the devices that make up CPSs in real life. To do this, we use the "Project based learning" method mentioned above, i. e. we choose a specific project. Students are introduced to the function that each component in the system performs individually (Fig. 1).

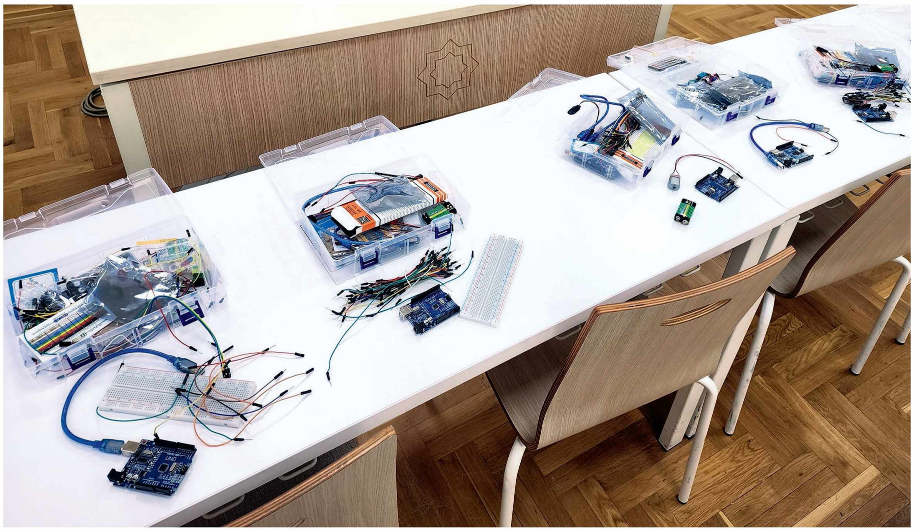


Fig. 1. Some components of the CPS for seeing and "touching"

Given the importance of group learning, we divide the group into sub-groups (student teams) of five to increase efficiency by comparing the tasks undertaken by the sub-groups. This creates a habit of working as a team and encourages the development of specific engineering skills, such as the ability to publicly explain new ideas and knowledge to team members.

Results and discussion

In this section we will discuss project selection, selection of components for real-time project execution, project execution and analysis of the results obtained as a result of project execution. The "Line following robot" project was chosen for the "Project based learning". The "Line following robot" consists of hardware and software and is a prime simple example of a CPS (Fig. 2).

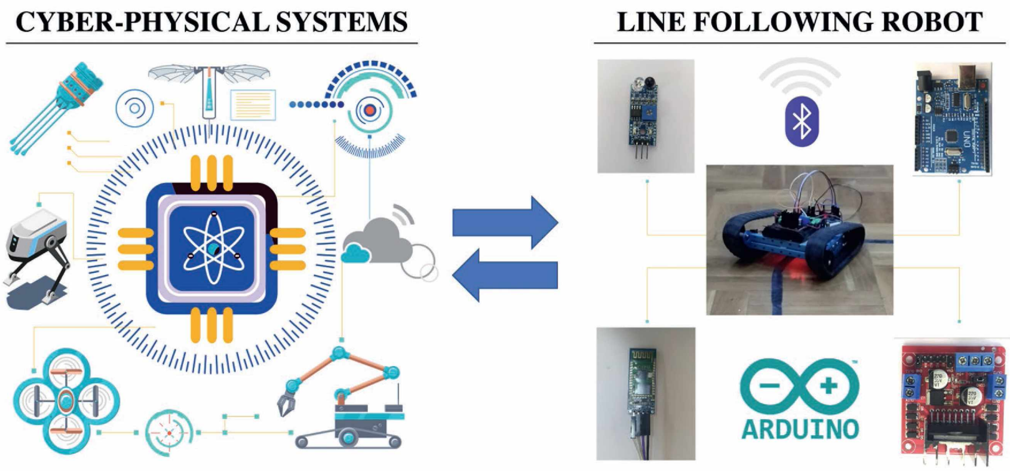
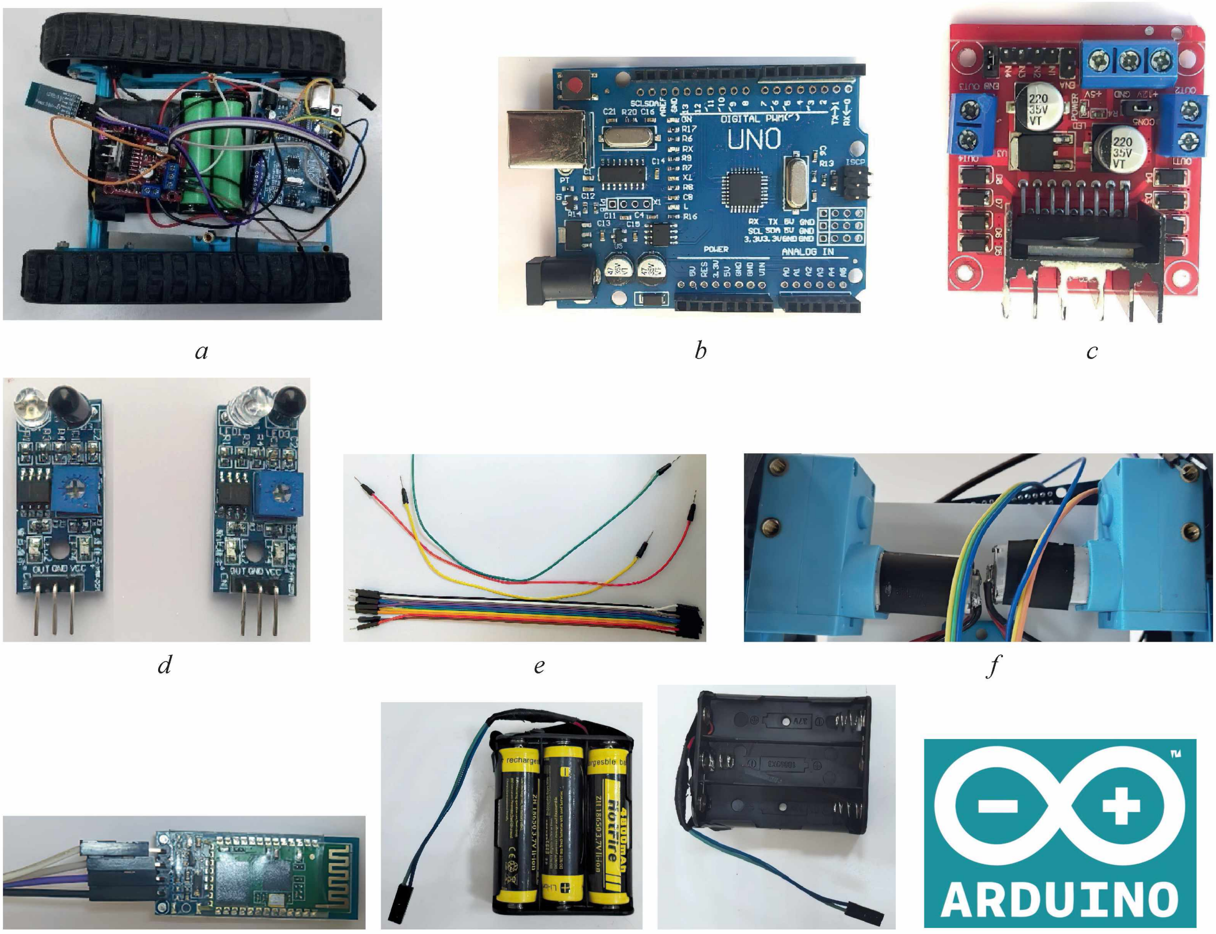


Fig. 2. "Line following robot" as and simple example of a cyber-physical systems

Line following robot is an autonomous robot which is able to follow a colored line that is drawn on the surface. As we can see from the definition, our robot must be able to follow a given line, i. e. it must be able to feel the line and receive information about it, for which we use an IR sensor. The next step is to process the data received from the sensor using the Arduino Uno platform and develop an algorithm for the program to send commands to control the DC motors and communicate with the wireless remote control. We use motor driver to control the movement and direction of the DC motors. We added the HC-06 Bluetooth module to this project to control the robot remotely in case of some technical problems.

This project allows students to interact in real time with sensors, actuators, data processing tools, programming and many others that are components of CPSs. Students are provided with all necessary equipment and components for the implementation of the project. The main goal of this project is to give students the opportunity to select the components of CPSs and develop an autonomous robot in the team that can move along the black line, controlled wirelessly (Bluetooth) if necessary, and to compare the performance of the teams with each other. The robot consists of the components depicted in Fig. 3.



a *b* *c* *d* *e* *f* *g* *h* *i* *j*

Fig. 3. Components of the line following robot: *a* – rolling chassis with wheels; *b* – Arduino Uno; *c* – motor driver L298N; *d* – IR sensors; *e* – connecting wires; *f* – DC motors; *g* – Bluetooth module HC-06; *h* – rechargeable batteries; *i* – battery box; *j* – Arduino software

The sub-group consisted of 2nd year students from the “Mechatronics and robotics majority”. These students had previously taken courses such as “Scientific fundamentals of innovative technologies”, “Physics”, “Mathematics”, “Mathematical statistics and probability theory”, “Programming” and “Engineering graphics” in different semesters. As the line following robot is controlled by the Arduino Uno platform, team members should be familiar with the Arduino programming language, as well as courses such as “Digital signal processing”, “Fundamentals of mechatronics”, “Fundamentals of robotics”. But the most important thing is not that they can fully understand these courses. The focus was on the students’ motivation and skills. Although the students had previously learnt the basic concepts in these courses, they did not complete the real project by ‘touching’ all the components. And this time they did a real project.

Sub-groups were formed taking into account the skills and abilities of the students. This is a common situation in engineering teams. The students are given a total of 48 hours to complete this project (16 hours of experimental lessons and 32 hours of additional lessons). The 16 hours of experimental lessons are carried out according to a timetable drawn up by the teachers (Tab. 1), and the 32 hours of extra lessons are carried out after the main lessons according to the timetable drawn up by the sub-groups themselves and agreed with the teacher.

Table 1. Examples of topics to be covered in the experimental lessons

No	Topic
1	An introduction to cyber-physical systems and some examples of them
2	Components of cyber-physical systems
3	Arduino platforms. The Arduino Uno platform
4	The Arduino programming language. Receiving data from sensors using the Arduino Uno platform
5	Controlling actuators with Arduino Uno
6	Digital signal processing with Arduino Uno
7	The line following robot and its components
8	Development of an algorithm for the movement of a line following robot on the Arduino Uno platform

Students carry out their research work in the relevant laboratories of the ETUT Scientific and Technological Center after the main classes. One of the main activities of the ETUT Scientific and Technological Center is to provide technical and methodological support to university teachers, graduate students, master and undergraduate students in conducting research and improving their education. Students and teachers of the Faculty of Cyberphysical Systems have carried out several scientific projects [18–26] at the Department of Intelligent and Robotic Technologies of the ETUT Scientific and Technological Center.

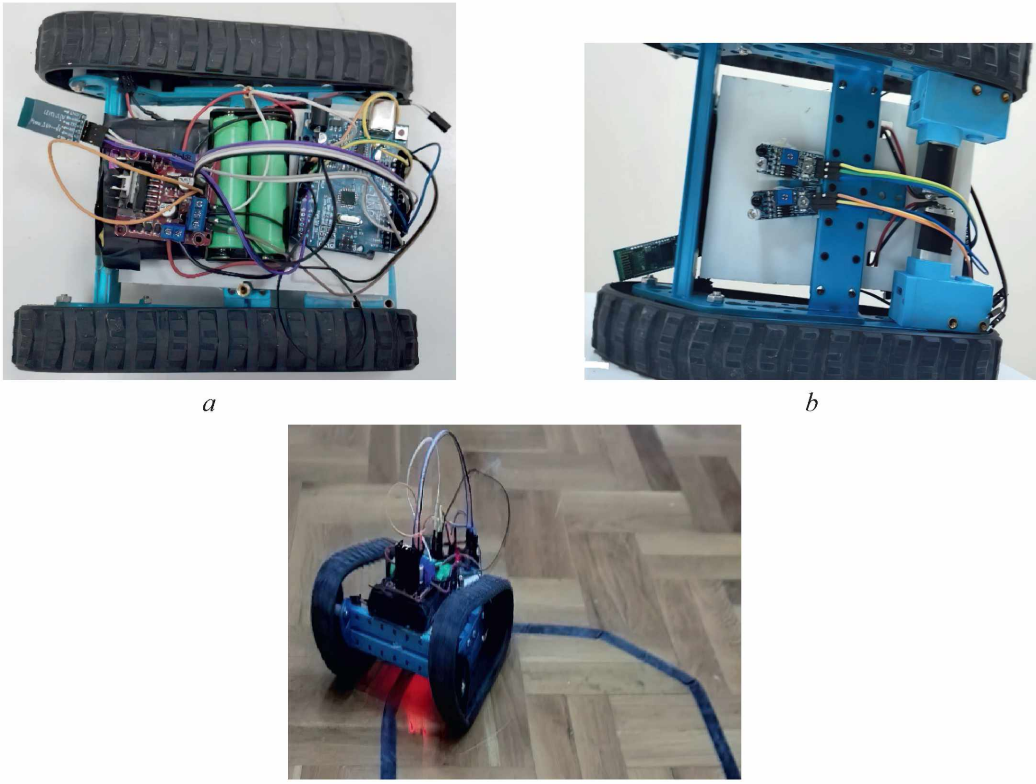
The main reason for the choice of the Arduino platform for the teaching of components of CPSs to students in experimental classes is the availability of open source projects on the same platform. Open source articles and video tutorials are presented in a way that is easy for students to understand, providing additional opportunities for self-learning and self-improvement. A further advantage is that the control system consists of both hardware and software components. The line following robot team project consisted out of four phases (Tab. 2).

Table 2. Phases of the line following robot team project

No	Phase
1	Choosing components and studying their purpose and working principles
2	Building the robot, putting all the components in their places
3	Developing and uploading a code algorithm for Arduino Uno
4	Testing the ready-to-use Line following robot experimentally

In the first phase, the students are explained the peculiarities of component selection and the technical characteristics of these components for each specific project. They are then introduced to all the components selected to build a line following robot, and the functions that each component performs. In the second phase, the components selected in the first phase are installed on the robot chassis together with the students. These components are then connected to each other, to the power supply and to the Arduino Uno by connecting wires. As a result, robots were built for each sub-group, as shown in Fig. 4.

In the third phase, the task is to move the robot configured in the previous stage. To do this, algorithms are created in the Arduino programming language for the motor driver that controls the DC motor, the IR sensor and the Bluetooth module. Each of these algorithms is loaded and tested individually on Arduino Uno controller. After checking the correctness of the algorithms, all of them are loaded with controls in the form of a single sequence of code. Fourth phase is the final decisive phase in our case, in which student teams test in real time the CPS they have developed – a line following robot. By observing the robot's movement along the line, they make the necessary adjustments to the code. Student teams can also control the robot using a smartphone via Bluetooth wireless connection. After each phase, the sub-groups presented their work. In the presentation, they presented a list of the literature used to complete this phase and what they learned from the relevant literature to complete this phase of the project. After the allotted 48 hours, all teams tested their completed projects on the track with lines. Some of the problems encountered with the prosthetics were discussed with other groups and teachers. Several competitions were organised to compare the projects with each other. When the students were asked for their opinion in order to determine the effectiveness of the teaching methodology used, they noted that for the first time they had mastered the skills of teamwork, explaining their ideas to each other, typical for engineers, and that they realized that what they had learned in the classroom could be applied in real life.



a *b* *c*

Fig. 4. Ready-to-use line following robot: *a*, *b* – top and bottom views, respectively;
c – line following robot in process

Conclusion

In this article the teaching method has been described where we have used to teach second year mechatronics and robotics majority students of the components of CPSs using a line following robot. Our aim is to give students the opportunity to learn how to work in a team and put it into practice. The students were given the basic information about CPSs and the opportunity to get to know each of the components that make up the CPS separately. During the 48-hour placement, the sub-groups worked as a team to build a line-following robot. In order to determine the results of the teaching method, the students were asked about the results. Students noted that after building the line following robot, their attitude towards CPSs changed and they became motivated to carry out larger projects related to CPSs. As a result of what they have learned in this course, we expect students to successfully complete course projects in their 3rd year and diploma projects in their final 4th year.

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Authors' contribution

Charyyeva A. A. made literature review, performed experiments with student teams, prepared figures.

Nokerov S. M. carried out the formulation of the problem for the study, proposed topics, suggested and provided information on the experiment, and prepared the manuscript of the article.

Hojagulyyev P. E. helped to perform experiments and prepare the manuscript of the article.

Orazov A. M. helped to perform experiments.

Venkataraman A. P. gave some practical recommendations.

Thulasi Bikku gave some practical recommendations.

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